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METHOD APPARATUS AND ARTICLE OF MANUFACTURE FOR  
BRANDING A DIAMOND WITH A FOCUSED ION BEAM

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BACKGROUND

10 I. FIELD OF THE INVENTION

The present invention relates generally to the field of the  
handling of precious gems and more specifically to the branding  
of a design onto a precious gem such as a diamond.

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II RELATED ART

In the handling, marketing and sale of precious stones, such  
as diamonds, as well as the sale of jewelry made from these  
precious stones, it is common practice for jewelers and diamond  
merchants to grade precious stones to determine their value based  
on such features as cut, weight, color and the purity of the  
crystalline structure of the stone. These attributes contribute  
to much of the value of an individual stone. Conventionally,  
these attributes are recorded on paper or other media separate  
from the stone itself. These attributes and the documents which  
record these attributes typically become a means of both  
determining the value of the stone and properly identifying its  
owner. Thus, because this information is so important, this  
information must be accurately and reliably conveyed to the

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purchaser of the stone during a sale or other transfer of ownership.

5 It is equally important to the owner of a particular piece of jewelry containing precious stones to be able to accurately identify the piece of jewelry and the individual stone or stones set in that piece of jewelry. Although most luxury and consumer  
10 goods carry serial numbers or other indications of ownership, so that owners can verify their ownership of goods of similar appearances, differentiate between genuine goods and counterfeit  
15 goods at purchase,

and have an indication of ownership for insurance purposes, this is, for the most part, not the case with precious stones. Although some stones are marked with the use of lasers, the vast  
20 majority of stones on the market today are unmarked. Currently, most consumers must rely on the representations of the jeweler who sells, cleans or works on the piece of jewelry that it is in fact authentic.

25 In addition to and concurrent with the security reasons which would make indelibly marking stones beneficial, the ability to indelibly mark stones would also be helpful for inventory control purposes. Specifically, both wholesalers and retailers of  
30 diamonds and other precious stones have no method of placing inventory control markings, such as bar codes indelibly upon stones.

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In addition to these reasons for indelibly marking stones, purchasers of stones frequently seek to personalize the stones or the jewelry in which they are set. Desired personalizations include messages, marriage certificates, and poems, as well as symbols and images.

Presently, accurate identification of precious stones for transmittal of attribute information or identification purposes is difficult because no commercially viable method for indelibly marking stones without defacing them and affecting their value is available. To preserve the value of the stone and still create an indelible marking on the stone, any marking or information placed on the stone must be extremely small, such that it is invisible to the naked eye, and preferably, to a 10X magnification power, which is the typical magnification power of a jeweler's loupe. However, it is apparent that the marking must be able to be detected in some manner for it to be of use.

Also, to ensure that markings are visible when a stone is mounted in a jewelry setting, any commercially successful marking system must be able to mark a stone on its "table," i.e. the large exposed top surface of the gemstone, rather than on the "girdle" or edge of the stone. This is because the girdle, or sections of the girdle, are frequently obscured or placed beyond view when a stone is set in a piece of jewelry. Additionally, because the girdle of the stone is a relative exposed portion of the stone, i.e., it is frequently where a stone is grasped when handled, it

is very easy to scratch off or damage any markings made on the  
girdle of the stone. Also, an ideally cut stone has very little  
5 flat surface at the girdle, but instead has a sharp edge. If a  
marking is to be made on the girdle of the stone, it is sometimes  
necessary to cut the stone in less than an ideal cut, so that a  
10 flat surface at the girdle of the stone can be created.

Examples of prior art systems which attempted to solve the  
problems of indelibly marking precious stones include U.S. Patent  
No. 4,392,476 to Gresser, et al., which describes the use of laser  
15 energy directed at the stone to inscribe the girdle of the stone  
with a desired marking; U.S. Patent No. 4,467,172 to Ehrenwald et  
al., which describes a laser system for inscribing permanent  
identification markings on or below the surface of the girdle of  
20 a diamond; and U.S. Patent No. 5,149,938 to Winston, et al., which  
describes a method of marking a diamond on its girdle by  
irradiation with an argon fluorine excimer laser whose output  
beam is passed through a mask which defines the marking.

25 One feature of each of these devices is their reliance on  
lasers. The use of a laser to cut or mark a diamond or other  
precious stone results in the disadvantages of the creation of  
microscopic cracks in the diamond as well as a "white-frosting"  
30 effect or a "dark-regions" effect which degrade the clarity of the  
diamond. These effects are especially pronounced when lasers are  
used to mark or brand the table of a diamond, rather than the  
35 girdle of a diamond. A still further disadvantage is that the

beams of most lasers are relatively wide and thus create large  
branding marks, i.e. large pixels as shown in Gresser, Fig. 3.  
5 This in turn limits the precision with which a marking can be  
made. Lasers also have limited ability to create "grey-scale"  
images which depend on contrast between adjacent "pixels." It  
10 will be understood that "grey-scale" images are created by  
varying the depth of the brand or pit which is cut into the  
surface of the diamond at a given pixel. Because it is very  
difficult to control the depth of a cut made by a laser, accurate  
15 and reliable "grey-scale" images are difficult to produce with  
lasers.

Accordingly, there is a need in the art for a method of  
indelibly marking a diamond or precious stone without damaging the  
20 clarity of the stone. Further, there is a need for these  
indelible markings to be of high resolution and for an indelible  
marking method to be capable of producing "grey-scale" images.  
The present invention includes these features, as well as other  
25 features and advantages as are described below.

#### SUMMARY OF THE PREFERRED EMBODIMENTS

30 In a preferred embodiment, a diamond is branded by first  
securing the diamond onto a holder capable of being used in a  
coordinate transfer system. Next, a coordinate transfer system  
is used to create a set of mapping data which represents the  
35 distances between the location on the diamond which will be

branded and certain set reference points on the holder. At the  
same time, a computer is used to convert a design to be branded  
5 on the diamond into design data capable of being processed and  
used by a focused ion beam machine. The mapping data is then used  
in conjunction with the design data to control the focused ion  
beam machine such that it produces a focused ion beam which  
10 impacts the diamond at a desired location for a desired length of  
time to brand the design onto the diamond.

15 BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 a perspective view of a diamond which has been cut and  
polished as a round brilliant cut.

FIG. 2 is a magnified, planar view of the portion of FIG. 1  
20 enclosed by Circle 2.

FIG. 3 is a flow chart illustrating the order of operation  
of the method of the present invention.

25 FIG. 4 shows a perspective view of a holder for diamonds in  
accordance with the present invention.

FIG. 5 illustrates an inverted, cross-sectional view of the  
holder of FIG. 4 along the line 5-5.  
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FIG. 6 schematically illustrates the positions of the  
diamonds and the reference points on a holder of the present  
invention.

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## DESCRIPTION OF THE PREFERRED EMBODIMENTS

5 In a preferred embodiment of the present invention, a diamond, such as the one illustrated in FIG. 1, is indelibly marked with a design by a focused ion beam machine. It will be understood that this invention can be used for the marking of other types of precious and semi-precious stones and that although  
10 the description which follows refers, by way of example, to the marking of diamonds, this description is not to be taken as limiting. With reference to FIG.1, a diamond 100 which has been cut and polished as a round brilliant has a table 102, which is  
15 the top-most surface of a diamond when it is placed in a setting such as a ring. For the particular cut of diamond shown, the table 102 is in the shape of an octagon. The diamond is visually  
20 separated into two portions, known as the crown 104, which is the upper portion of the diamond, and the pavilion 106, which is the lower portion of the diamond. The crown and pavilion are separated by a girdle 108. The diamond also has a number of different  
25 facets 110 which serve to give the diamond its unique shape, its light refracting properties, and which naturally define edges 112 between facets.

30 A portion of the table 102 encircled by Circle 2 is shown magnified in FIG. 2. With reference to FIG. 2, the edges 200 correspond to the edges 112 between the table 102 and several facets of FIG. 1. A design 202 is branded into the surface of the  
35 table 102. It will be understood by one of ordinary skill in the

art that, based on the explanation below, the design could consist  
of images, bar codes, numbers or letters which are necessary to  
5 identify the stone, describe its attributes, mark the stone with  
a trademark of the manufacturer, engrave a personal inscription,  
mark the stone with a family crest, a copy of a photograph or  
10 whatever other marking might be desired by the user or purchaser.

It is preferred that the branded design is located on the table  
of the diamond. This allows the brand to be observable by a  
microscope even when the diamond is placed in a jewelry mount or  
15 setting such as a ring. If the brand is located on the girdle or  
the pavilion, it can be obscured by a prong of a setting when the  
diamond is placed in a ring, thus frustrating the identification  
aspect of the present invention.

20 The design 202 is about two-hundred and fifty (250)  
micrometers wide, however the present invention is capable of  
producing a brand as small as seven (7) nanometers wide. At about  
250 micrometers, the design is small enough that it will not be  
25 visible to the naked human eye, and will be difficult to detect  
with a jeweler's loupe, but will be visible with a an optical  
microscope with a magnification of 100X. This is the result of  
the shallow depth of the brand, which is preferably no more than  
30 20-40 nm. Alternatively, it is possible to produce a brand of  
greater depth (such as, for example as deep as 120 nm) with the  
concurrent advantage of providing greater resolution for grey-



scale images, however, deeper brands may be visible to a jeweler's loupe under certain circumstances.

5 In a preferred embodiment, the design 202 is composed of graphite bonded to the surface of the diamond and included beneath the surface of the diamond. This embodiment allows the design to be effectively viewed by an infra-red microscope in addition to  
10 an optical microscope, because graphite is a good conductor of electricity, while diamond is not a good electrical conductor. As a result, when viewed by an infra-red microscope, design 202 will appear as a bright white image, while the surrounding diamond  
15 will be a dark grey color. Alternatively, this graphite can be removed, as described below, leaving a design in the form of a carving of varying depths in the surface of the diamond.

20 With reference to FIG. 3., processing begins by selecting the diamonds to be branded 300 and then cleaning them 302 before branding. It will be understood that the cleaning process can be accomplished by any acceptable process for cleaning diamonds such  
25 as immersion in an ultrasonic bath of isopropyl alcohol. Next, the diamonds must be secured to a holder which is capable of being used in a coordinate transfer system 304.

30 An example of one such holder 400 is shown in FIG. 4 and includes a base 402 which is composed of an electrically conductive material such as copper or aluminum. At regular intervals, holes 404 have been formed through the base 402 of the  
35 holder which generally correspond in circumference to the

circumference of a cut diamond. With reference to FIG's. 4 and 5, the holder 500 has a plurality of holes 502 drilled through from the top side 504 to the bottom side 506 each hole 502 is approximately the same circumference as the circumference of a diamond to be mounted in the holder. To mount the diamonds, the holder is placed upside down, as shown in FIG. 5 so that the top side 504 is in contact with a silicon wafer 507, or some other suitable extremely level and uniform surface. One diamond 508 is inserted into each hole 502 such that its table is in contact with the silicon wafer or level surface. Once all of the diamonds to be mounted are placed in the holder, a plug 510 is inserted into the hole 502 to secure the diamond. Each plug has a small depression 512 carved in its top 514 which conforms roughly to the shape of the pavilion 516 of the diamond 508 to be mounted. Each plug is composed of a conductive material such as copper or aluminum. Each plug is secured to a diamond and the holder itself by a suitable amount of electrically conductive paste 518 or other material capable of creating a conductive bond. Preferably, the paste is composed of graphite and 2-propanol and when dry bonds the diamond to the topside of the plug 514 and also bonds the top of the plug 514 to the holder 500. Enough adhesive should be used to secure the diamond to the holder 400 so that it will not move while the holder is being handled and processed by both the coordinate transfer system and the focused ion beam machine.

It will also be understood by one of ordinary skill in the art that more than one diamond can be placed in the holder at a time, and that the number of diamonds which can be processed by the coordinate transfer system at a time is limited only by the size of the holder that the particular coordinate transfer system used will accept. It will be further understood that the holes 404 can be formed to accept various cuts of diamond and precious stone and that the present invention is not limited to the round brilliant cut which is illustrated. While it is preferable that the diamond be oriented so that it can be branded on its table, the present invention is capable of modification to allow branding on any surface of a diamond. The holder 400 also includes at least three reference points 408 which are used by the coordinate transfer system.

The diamond must also be coated with a thin conductive layer 306. Preferably this layer is no more than ten (10) nanometers thick. Because the surface of a diamond builds up a positive charge, in order for a positively charged focused ion beam to effectively impact the diamond, the surface of the diamond must be charged neutral. In a preferred embodiment, the diamond is coated with a thin coating of carbon particles. This may be accomplished by a carbon-coater such as the Cressington Scientific Instruments 108 Carbon, manufactured by Cressington Scientific Instruments. Alternatively, the conductive layer can be composed of any suitable conductive material such as, for example, gold,

platinum, or chromium. In another embodiment of the invention,  
a charge neutralizer (also called a "flood gun") can be used to  
5 neutralize the positive charge built up on the surface of the  
diamond prior to and during branding with a focused ion beam. It  
will be understood that the order of steps 304 and 306 can be  
10 reversed, i.e. that the diamond may first be carbon coated and  
then subsequently secured to a holder.

Next, the holder is inserted by an operator into the  
coordinate transfer system. An example of one such coordinate  
15 transfer system is the JMAR Mirage, which is manufactured by JMAR  
Precision Systems, Inc. of San Diego, California. The JMAR Mirage  
is an extremely accurate tabletop automatic measuring system with  
an X-Y-Z travel of 10" x 4" x 2". The JMAR Mirage includes high  
20 powered microscope objectives and can be used with or without a  
laser autofocus for high speed Z-axis measurement and on-the-fly  
focusing of a video image of the object being measured.  
Optionally, the JMAR Mirage may also include microscope optics  
25 using a two-position precision automatic lens shuttle.

The JMAR Mirage then develops accurate mapping data for the  
diamonds in that holder, as indicated in block 308. The holder  
400 shown in FIG. 4 is shown schematically in FIG. 6. The holder  
30 400 includes holes with diamonds secured in them 602. For  
purposes of explanation, the table portion of each diamond 602 is  
shown as an octagon. The holder also includes a first reference  
35 point 604, a second reference point 606 and a third reference

point 608. Preferably, each of the three reference points has a sharp distinguishable corner that can be easily identified by the video-imaging system of the JMAR Mirage. The three reference points are located at the outermost edges of the holder and are aligned with the rows of diamonds. Also preferably, the three reference points are each formed to a different predetermined depth into the base 402 of the holder, to allow for calibration of the "Z" axis by the JMAR Mirage.

The JMAR Mirage system identifies the first reference point 604 and uses it as a base point for an X-Y coordinate system. The JMAR Mirage system accurately identifies the first reference point by using its video imaging system to locate the reference point, identify the edges of the reference point, and then fix the relative position of this reference point in its memory. This same process is then performed to locate and fix the second reference point 606, and the third reference point 608. This measuring results in the creation of an X-Y coordinate axis based on the fixed locations of the reference points. For convenience, an X-Y axis 610 is indicated in the drawing. The JMAR Mirage then proceeds to impose this coordinate system on the holder and to measure how far each diamond is from the first reference point 604 and the second reference point 606; i.e. the horizontal and vertical offsets. The JMAR Mirage further determines the exact locations of every visible surface of the diamonds secured to the holder 600. The JMAR Mirage also uses first reference point 604

and second reference point 606 to determine a reference line 612. The reference line 612 is in general alignment with the rows of  
5 diamonds in the holder 600. Each diamond 602, however, will not be perfectly aligned with the reference lines 610. Specifically, one edge 614 of the octagon shape that forms the table of the  
10 diamond is generally parallel with the reference lines 610, but at the microscopic scale, the edge 614 of the table each diamond will be rotated slighted away from being perfectly parallel. The JMAR Mirage determines the angle by which the edge 614 of each  
15 diamond is out of parallel alignment with reference lines 610. Using the JMAR Mirage Imaging system to first locate a corner on a diamond, then focus on one edge of the diamond and then trigonometrically determine both the branding point and the angle  
20 between the edge of the diamond and the reference line. This angle indicates how far the diamond is out of alignment from the reference line and allows the JMAR Mirage to determine a rotation value. This rotational offset data will subsequently allow the  
25 focused ion beam machine to brand each diamond such that the design on each diamond is correctly positioned with reference to an edge 614 and so that design is "lined-up."

30 The JMAR Mirage is controlled by a computer to accomplish the functions described above. It will be understood by one of ordinary skill in the art that these functions are preferably programmed in autoTHP, but could be implemented in other  
35 programming languages. Similarly, minor modifications and

variations can be made to the code without departing from the scope of the present invention.

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After these functions are carried out, a set of mapping data which consists of an X-Y-Z coordinate system mapping the locations of the diamonds, as well as rotational data, has been developed. This mapping data is then transmitted to the focused ion beam machine, as shown in FIG 3, block 310.

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While the diamonds are being processed as described above, the design to be branded onto them must also be processed. This begins when the operator determines the design to be applied to a diamond, or if multiple diamonds are placed in a holder, when the operator determines which design will be applied to each diamond 312. Next, the design is input into a computer by optical scanner, or electronic means such as a file transfer from a storage medium. The computer then converts the design into stream files which create a local coordinate system for the design, and then assigns  $X_1$ - $Y_1$ - $dt$  values to this coordinate system representing the design as shown in block 314.

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After these functions are carried out, a set of design data has been developed. This design data is then transmitted to the focused ion beam machine, as shown in FIG 3, block 316.

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It will be understood that the  $X_1$  and  $Y_1$  values will be mapped to and, when the design is branded on the diamond, these values will be integrated into the X-Y coordinate system in the mapping data. The  $dt$  data is the darkness or contrast of each

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individual pixel shown in the design. When the design is branded  
onto the diamond, the depth of the brand will be varied by varying  
5 the amount of the time in which the ion beam strikes the surface  
of the diamond. This in turn varies the relative darkness of that  
pixel of the brand.

10 It will be understood that this process can be done before,  
after, or simultaneously with the process of selecting and  
measuring the diamonds. However, for maximum efficiency and  
output from the process, it is preferred that the selection and  
15 conversion of the design be done simultaneously with the selecting  
and measuring of the diamonds to be branded.

Next, a computer controlling the focused ion beam machine  
receives both the mapping data and the design data. The focused  
20 ion beam machine itself is preferably a Gallium ion based machine.  
However, any liquid metal or gas based focused ion beam machine  
would be acceptable. An example of one such machine which is  
suitable for the process disclosed is the FIB 200 THP,  
25 manufactured by FEI Company of Hillsboro, Oregon. The computer  
maps the local coordinate system of the design to be branded,  
which is a part of the design data, onto the global coordinate  
system which is contained within the mapping data. The computer  
30 then uses this merged data to control the focused ion beam machine  
to accurately direct the focused ion beam so that it strikes the  
surface of the diamond to be branded at a particular location for  
35 a particular amount of time such that the surface particles of the



diamond which are impacted by the ion beam are converted into graphite.

5 After these functions are carried out, the diamond or diamonds in the holder are branded and the design is formed in graphite set into the surface of the diamond.

10 Optionally, this graphite can be removed as shown in block 320. This can be accomplished by a number of different methods, but is preferably done by exposure to potassium nitrate ( $\text{KNO}_3$ ) at  $500^\circ\text{C}$  for approximately forty minutes in a ceramic crucible.

15 Alternately, the carbon can be removed by exposing the diamond to an oxygen plasma. As one of ordinary skill in the art will appreciate, the diamond to be cleaned is placed in the vacuum chamber of a plasma cleaning system, such as the Plasmod,

20 manufactured by March Instruments of Concord, California. A gas, typically oxygen, is introduced into the chamber and electrically charged to create a reactive plasma. The plasma reacts with the graphite and removes it, while leaving the diamond untouched. The

25 by-products of this reaction are then removed by a vacuum pump. Finally, removal of the graphite can also be accomplished by immersion in an acid bath.

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#### CONCLUSION

The foregoing description of the preferred embodiment of the invention has been presented for the purposes of illustration and

35 description. It is not intended to be exhaustive or to limit the

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invention to the precise form disclosed. It is intended that the  
scope of the invention be limited not by this detailed  
5 description, but rather by the claims appended hereto.

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